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MEASUREMENT OF ABSOLUTE LUMINOSITY

YIELD OF POWDERED PHOSPHORS

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ABSTRACT

Deficiencies in present methods of luminosity yield measurements are discussed; an improved method is shown. Absolute yield was determined for two phosphors, $ZnS \cdot Cu$ and $Zn_2SiO_4 \cdot Mn$, giving average readings, and quantum yield over the Stokes excitation region is discussed.

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The question of the energy balance associated with the absorption and radiation of light during luminescence phenomena is of great practical and theoretical interest (ref. 1). Whereas for a series of dye solutions an evaluation has been made of the absolute luminosity yield as well as of the variation of the wavelength of the excited light (ref. 2), data of this type are absent for phosphors. The reason for this is the difficulty of carrying out absorption measurements due to the scattering of light by the phosphor which usually consists of a very fine crystalline powder.

During the conference on luminescence which took place at Oxford in 1938 (ref. 3) the problem of measuring the absorption of powdered materials by means of a photometric sphere resulted in a large discussion which showed the deficiency of the proposed methods. According to data published in the literature (ref. 4), the measurements of the absolute luminosity yield were accomplished
*Numbers in margin indicate pagination in original foreign text.

only for individual wavelengths of the exciting light.* Usually these were limited to two or three wavelengths.

The method proposed by us utilizes the sphere whose inner surface, contrary to conventional photometric spheres, is covered with the test material—in the present case with the phosphor. In addition to this, the absorption of light by luminescence inside the sphere is taken into account by sending light into the sphere which is close in color to the color of luminescence. This method was applied by one of us (ref. 6) while measuring the absolute yield of scintillation produced by the phosphors under the action of "red" light.

A sphere with a diameter of ~30 mm was constructed from fused quartz and contained double walls ** (Fig. 1) and the phosphor was poured into the space between these two walls through a special opening in the external wall. The thickness of the layer which was equal to the clearance between the walls was approximately 2 mm. In practice this layer was infinitely thick since the light did not penetrate the external walls of the sphere. Two openings were made in the sphere through both walls and were placed so that they were along two mutually perpendicular axes of the sphere. One of them (with an area s_1) was used to introduce the radiation, while the other (with an area s_2) was used to observe the emitted light. The light into the sphere was directed from a mercury lamp after passing a double quartz spectroscope.

As we know, the absolute energy yield η is the ratio of the radiated

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* Measurements over a wide range of the spectral region (ref. 5) were carried out only for the phosphor KCl·Tl which had the form of large monocrystals.

** The sphere was fabricated by A. V. Petushkov.

energy P to the absorbed energy Q_{λ} (at a given wavelength λ) which can be measured in the same relative units:

$$\rho_{\lambda} = P/Q_{\lambda}, \quad (1)$$

The quantity Q_{λ} is apparently equal to the difference between the energies entering the sphere (through s_1) and coming out of the sphere (through s_1 and s_2) which has not been absorbed by the phosphor:

$$Q_{\lambda} = s_1 E_{0\lambda} - s E_{\lambda} = s_1 E_{0\lambda} \left(1 - \frac{s}{s_1} \frac{E_{\lambda}}{E_{0\lambda}}\right), \quad s = s_1 + s_2, \quad (2)$$

where $E_{0\lambda}$ is the density of the incident radiation while E_{λ} is the density of the outgoing radiation.

$E_{0\lambda}$ was measured directly with a thermopile; E_{λ} for a series of reasons could not be measured in this way.* Therefore a photometer was used to make a relative evaluation of the quantities $E_{0\lambda}$ and E_{λ} from the brightness $B_{0\lambda}$ and B_{λ} of the luminescent layer which was first placed before the exit slit of the spectroscope and then into the plane of the output hole of the sphere. To eliminate interference produced by the luminescence of the sphere itself during photometry, a light filter was placed before the eye which did not transmit the green light of the test phosphor and which trans-

* First of all the quantity E_{λ} is very small since the sphere absorbs the exciting light almost complete. Furthermore the dimensions of the thermopile are such that it cannot be inserted into the opening in the sphere. Furthermore the construction of conventional thermopiles does not make it possible to sense radiation over a wide solid angle.

mitted only the red luminescence of the layer (even though partially). We therefore have the obvious ratio

$$E_\lambda / E_{0\lambda} = B_\lambda / B_{0\lambda}.$$

Then in place of (2) we obtain the following final expression for the absorbed energy which contains only the measured quantities:

$$Q_\lambda = s_1 E_{0\lambda} \left(1 - \frac{s}{s_1} \frac{B_\lambda}{B_{0\lambda}} \right). \quad (3)$$

There are certain difficulties associated with determining the radiated energy P . The luminescence produced inside this sphere by the exciting light is only partially released from the sphere. The evaluation of the entire radiated energy was made in the following manner. A monochromatic light was sent into the sphere such that its color was close to the color of luminescence. If we assume that the absorption coefficient for the monochromatic light is the same as for the luminescent light,* then the portion of the outgoing monochromatic light may be considered to be equal to the portion of outgoing luminescent light.

Indeed, in spite of the difference in the conditions of the first scattering (in one case it takes place with light radiated by the phosphor layer while in the other the light enters this layer from the outside), the basic quantity

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* The coefficients of absorption would coincide in an ideal fashion if luminescent light from the same phosphor were to be sent into the sphere.

of light, due to a large reflection coefficient of the phosphor powder in the visible region, leaves the sphere only as a result of multiple scattering. In this case the difference which in itself is insignificant, in the first case of scattering, will practically have no effect on the amount of outgoing light.

The density of visible radiation E_{λ_0} , going out from the spectroscope was measured in the same manner as for the case of the ultraviolet light, by using a thermopile. The evaluation of the visible as well as of the fluorescent light coming out of the sphere was achieved by using a photometer to measure the respective brightnesses B'_{λ_0} and B_Φ of frosted glass placed in a plane of the output opening of the sphere. In this case, in accordance with what we have stated above, the following ratio must exist which determines P in terms of the measured quantities:

$$\frac{P}{E_{\lambda_0} s_1} = \frac{v_{\lambda_0} B_\Phi}{v_\Phi B'_{\lambda_0}}, \quad (4)$$

where v_{λ_0} is the visibility factor of light for wavelength λ_0 and v_Φ is the average visibility factor for the luminescent light

$$v_\Phi = \frac{\int_0^\infty v_\lambda I_\lambda d\lambda}{\int_0^\infty I_\lambda d\lambda},$$

I_λ is the relative distribution of energy in the spectrum of luminescence.

From (1), (3) and (4) we finally obtain an expression for the absolute energy yield

$$\rho_{\lambda} = \frac{v_{\lambda_0}}{v_{\Phi}} \frac{B_{\Phi} E_{\lambda_0}}{B'_{\lambda_0} E_{0\lambda}} \frac{1}{1 - \frac{s_1 B_{\lambda}}{s_2 B_{0\lambda}}} \quad (5)$$

The absolute quantum yield is

$$\rho'_{\lambda} = \rho_{\lambda} \frac{\lambda_{\Phi}}{\lambda}, \quad (6)$$

where λ_{Φ} is the average wavelength of the luminescence band

$$\lambda_{\Phi} = \frac{\int_0^{\infty} \lambda I_{\lambda} d\lambda}{\int_0^{\infty} I_{\lambda} d\lambda}.$$

Measurements of the absolute yield were carried out for two phosphors $ZnS \cdot Cu$ and $Zn_2SiO_4 \cdot Mn$ * (Fig. 2). Each point represents the average of two readings. Different points for $Zn_2SiO_4 \cdot Mn$ correspond to different series of measurements. 1486

Contrary to the situation which occurs when we have solutions of dyes and of the phosphor $KCl \cdot Tl$, under the given conditions of excitation (ref. 7) there is no constancy in the quantum yield over the entire Stokes region of excitation. For the phosphor $ZnS \cdot Cu$ the quantity ρ'_{λ} assumes a maximum value equal to approximately 0.5 near $360 m\mu$. On both sides of this maximum ρ'_{λ} drops rather slowly. The picture is different for the phosphor $Zn_2SiO_4 \cdot Mn$. From approximately 310 to $260 m\mu$, ρ'_{λ} increases very rapidly almost from

* The values of ρ'_{λ} for $Zn_2SiO_4 \cdot Mn$, obtained by M. N. Alentsev (ref. 7) by an entirely different method are in agreement with our data.

zero to a value of approximately 0.6 which, as far as we can judge from the accuracy of the measurements, apparently remains unchanged up to approximately $220 \text{ m}\mu$.

The calculations and measurements of the absolute yield can be simplified if instead of directing a light of wavelength λ_0 into the sphere we use the luminescence produced by the same phosphor as the one which is under test (in equation (5) the visibility coefficients in this case are reduced because $v_{\lambda_0} = v_{\Phi}$), and if the opening in the sphere is made sufficiently small so that we can neglect the outgoing exciting light * ($s_B \ll s_1 B_{0\lambda}$). In this case equation (5) takes on the following simple form ($E_{\lambda_0} = E_{\Phi}$ and $B'_{\lambda_0} = B'_{\Phi}$):

$$\rho_{\lambda} = \frac{B_{\Phi} E_{\Phi}}{B_{\Phi} E_{0\lambda}}. \quad (7)$$

In equation (7) $E_{0\lambda}$ and E_{Φ} are measured with a thermopile using an almost parallel beam while B_{Φ} and B'_{Φ} are measured with a photometer which has frosted glass placed at the output opening of the sphere.

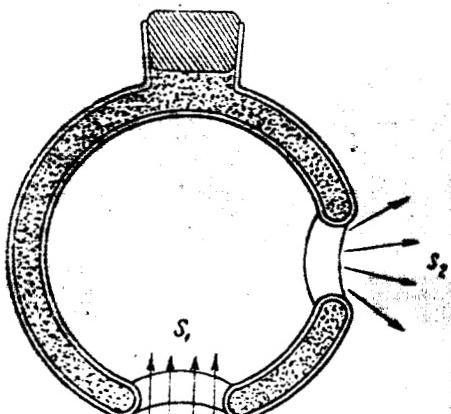


Figure 1.

* In the case $\text{ZnS} \cdot \text{Cu}$ and $\text{Zn}_2\text{SiO}_4 \cdot \text{Mn}$ the portion of outgoing exciting light varies fourteen to three percent and less.

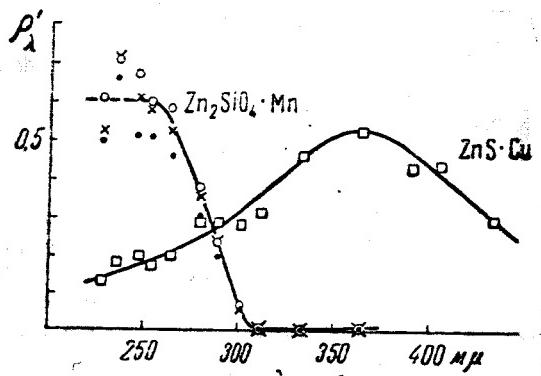


Figure 2

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